Non-Linear analysis of the stress–strain behavior of unsaturated soil in response to earthquakes

Mehran Naghizadehrokni

PhD Researcher at RWTH Aachen University

My reasons and the purpose of undertaking this project

The climate of an area imposes specific environmental conditions on it. One of the most influential circumstances in a region is its soil moisture content. Any changes in soil moisture status will effect soil conditions. When the soil is not quite saturated or is dry, these soil conditions are commonly known as “partially saturated” and “unsaturated”. Almost 40% of the natural surface soil globally is unsaturated. The soil in the vicinity of the surface layers are more influenced by climatic, physical and environmental factors and their water content will be more variable [1].

One important mechanical and physical property of soil and aggregate dependence is the level of stress and strain. Determination of the basic relationship for expression of stress-strain in soil is difficult and prediction of the behavior of all features in a model is practically impossible. Analysis and determination of the distribution of stress and strain in soil in geotechnical structures has traditionally been based on Hooke's law of elastic linear behavior. The introduction of nonlinear elastic models was a new step forward for models in the prediction of the behavior of soil. The stress-strain curve of unsaturated soil is much more complex and varied than for saturated soil and must be described properly by basic models in relation to the conditions of unsaturated soil.

Environmental factors and the passage of time create a natural soil structure. Structure and soil texture play an important role in its geotechnical features. Another important parameter for determining the stress-strain behavior of soil is soil type. The soil type and higher percentages on gradation curves indicate that certain substances can change the behavior of soil.

Dynamic parameters are essential to the analysis and design of geotechnical structures in nonlinear analysis under dynamic loading. It is essential to have sufficient information about the response and behavior of unsaturated soils under loading to design and build safe and economic structures. Cyclic loading on the foundations can be caused by coastal waves, wind, operating machinery, wind turbines and earthquakes. The addition of cyclic loads increases the pore pressure in the soil. In sandy soil, if the magnitude and number of cycles of loading are high and the periods of the soil and earthquakes are close, the resulting pore pressure will be equal with effective stress between the soil particles and soil shear strength will decrease with the destruction of the interaction between sand grains. A decrease in soil strength and stiffness can cause damage in whole or in part of foundation and can create a substantial mass settlement of soil. Plastic strain is a major cause of high settlement foundations under cyclic loading [2].

Lack of consistency between the laboratory tension-strain charts (triaxle testing) and the results of the proposed models for saturated soils is a problem facing researchers. A change in the behavior of soil caused by a change in the soil saturation parameters and dynamic loading are crucial issues in the design of geotechnical structures. The safety of these structures require accurate understanding of soil behavior.

My research project

This study will design a simple model for saturated soil under elastic-plastic unsaturated soil conditions to determine the effects of dynamic loading from earthquakes on soil. The Barcelona theory will be used determine a model for the Bishop effective stress hypothesis (assuming constant residual strength) and borderline levels of critical loading. Changes in the normal consolidation soil line in the two-dimensional space of porosity in the soil confining pressure caused by the increase or decrease saturation of soil samples will be examined.

For this purpose, models of behavior set by numerical models will be applied on the normal samples. The results of saturated and unsaturated triaxle tests on soil samples under especially normal stresses and different suctions will be compared in dry weather and wet obtained by Alonso [3]. Using the results, effective stress parameter is obtained for the unsaturated soil condition and in conditions of constant suction, stress-strain curves in dry conditions compared with their wet states.

Research Aims

1- Determination of the equations governing the stress-strain behavior of unsaturated soil under earthquake loading
2- Check suction changes in unsaturated soil under seismic loading
3- Determine the effect of an earthquake on changes in effective stress during consolidation
4- Assess changes in saturation on the soil shear strength at different levels of loading

Questions for research may include the following:

1- How do changes in soil saturation effect the soil stress-strain curve?
2- What is the effect of dynamic loading of soil on soil pore water pressure, plastic strain and effective stress curves?
3- What is the effect of dynamic loading on unsaturated soil shear stress of the soil sample?
4- When will the soil suction-saturation curve shift to dynamic loading?

Methodology

The most important factors for modeling of elastic-plastic behavior of saturated soil are [4]:

1- Changes in behavior of soil occur according to the water saturation of the soil.
2- The hydraulic behavior of soil is dependent on factors such as suction, saturation, and porosity changes.
3- Changes occur in the effective stress of soil under seismic dynamic loading.

The study will evaluate hydraulic hysteresis effect by composing a chart of unsaturated soil behavior versus the percentage of soil saturation. This curve will be used to expand the classical relationship with water retention curves.

Refrences

[1] Arairo, Wahib, et al. "A new insight into modelling the behaviour of unsaturated soils." *International Journal for Numerical and Analytical Methods in Geomechanics* 37.16 (2013): 2629-2654.
[2]Fredlund, Delwyn G., Harianto Rahardjo, and Murray D. Fredlund. *Unsaturated soil mechanics in engineering practice*. John Wiley & Sons, 2012.
[3] Alonso, E.E., Gens, A., and Josa, A. (1990). “A constitutive model for partially saturated soils.” Géotechnique, 40(3), 405-430.
[4] Kyokawa, H., et al. "Simple modeling of stress-strain relation for unsaturated soil." *Geotechnical Special Publication of American Society of Civil Engineers (ASCE) on Experimental and Applied Modeling of Unsaturated Soils, June* 202 (2010): 17-25.